Color:
Color spaces

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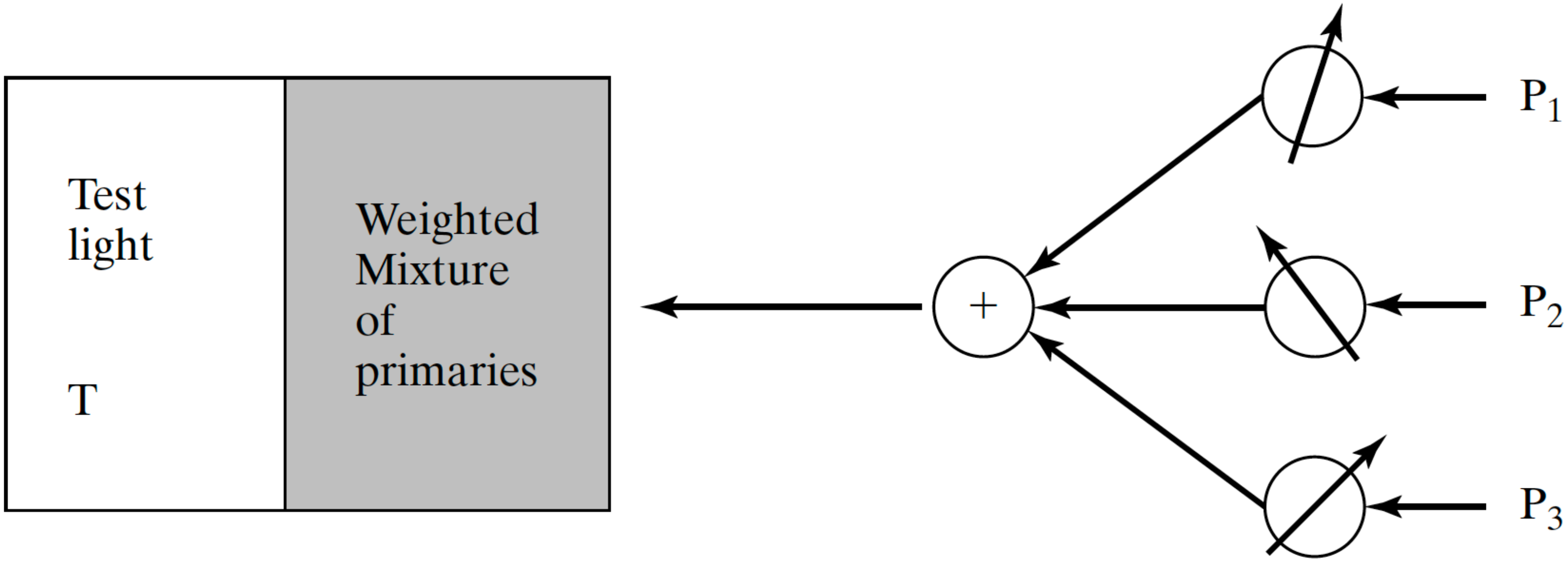
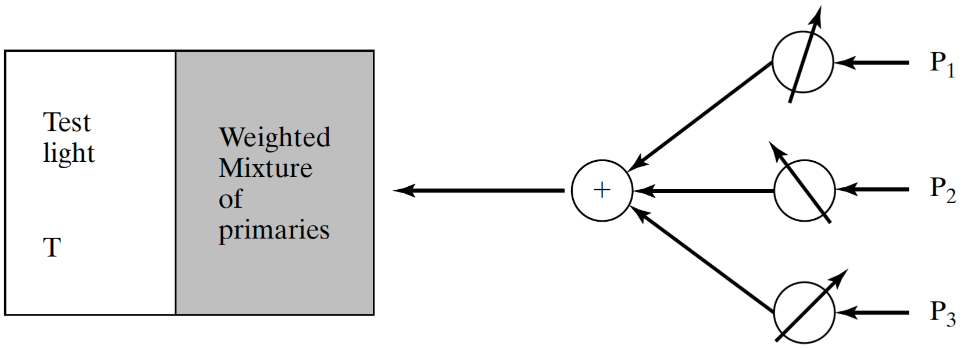
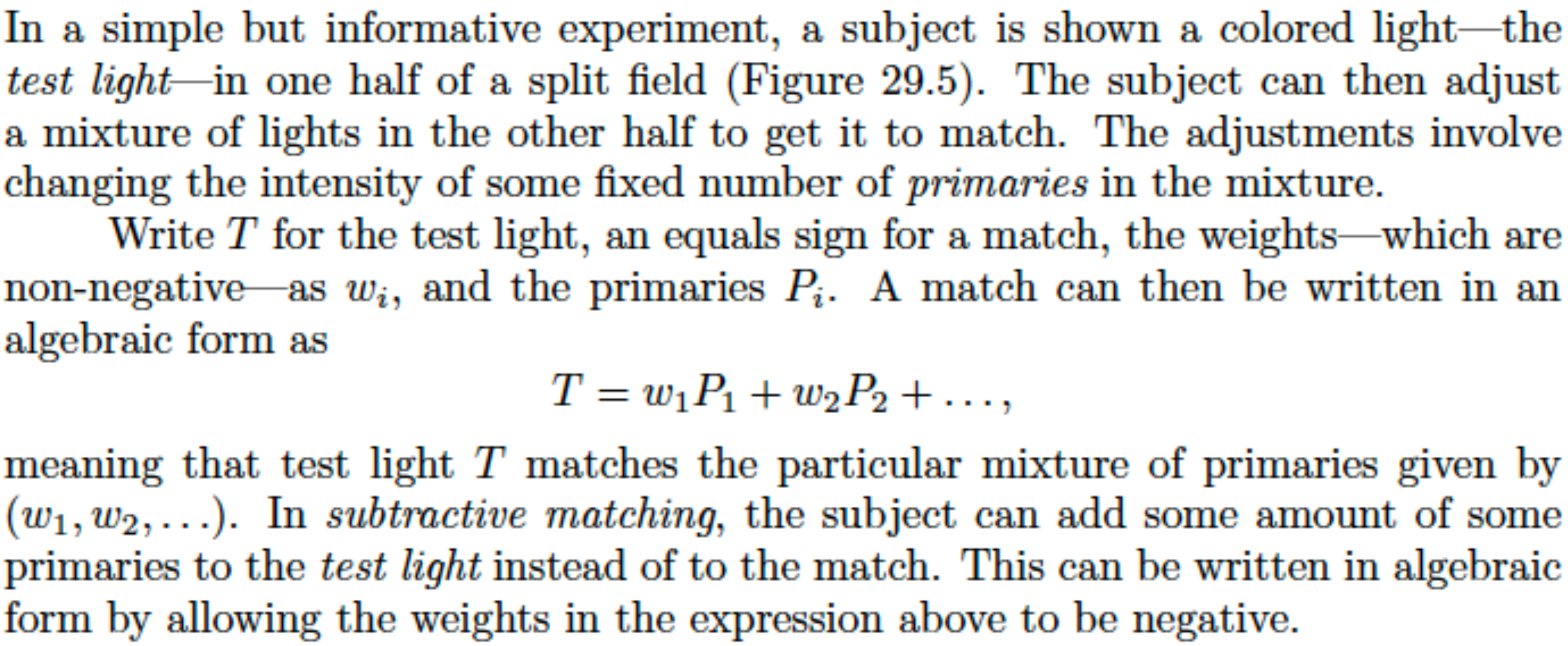
Color matching experiments - I



Color matching experiments - II





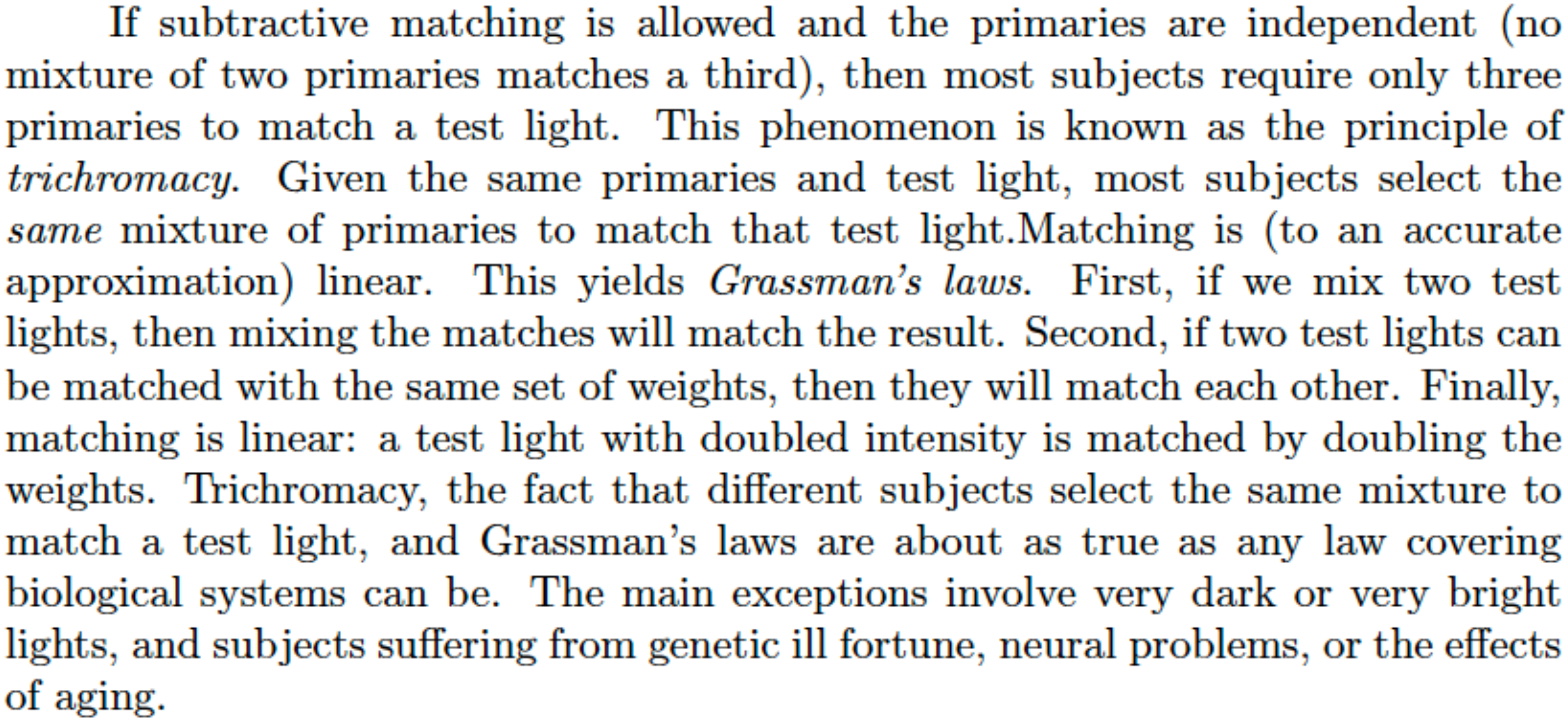
In a simple but informative experiment, a subject is shown a colored light—the *test light*—in one half of a split field (Figure 29.5). The subject can then adjust a mixture of lights in the other half to get it to match. The adjustments involve changing the intensity of some fixed number of *primaries* in the mixture.

Write T for the test light, an equals sign for a match, the weights—which are non-negative—as w_i, and the primaries P_i. A match can then be written in an algebraic form as

$$T = w_1 P_1 + w_2 P_2 + \dots,$$

meaning that test light T matches the particular mixture of primaries given by $(w_1, w_2, \dots)$. In *subtractive matching*, the subject can add some amount of some primaries to the *test light* instead of to the match. This can be written in algebraic form by allowing the weights in the expression above to be negative.

Trichromacy and Grassmann’s laws



If subtractive matching is allowed and the primaries are independent (no mixture of two primaries matches a third), then most subjects require only three primaries to match a test light. This phenomenon is known as the principle of *trichromacy*. Given the same primaries and test light, most subjects select the *same* mixture of primaries to match that test light.Matching is (to an accurate approximation) linear. This yields *Grassman’s laws*. First, if we mix two test lights, then mixing the matches will match the result. Second, if two test lights can be matched with the same set of weights, then they will match each other. Finally, matching is linear: a test light with doubled intensity is matched by doubling the weights. Trichromacy, the fact that different subjects select the same mixture to match a test light, and Grassman’s laws are about as true as any law covering biological systems can be. The main exceptions involve very dark or very bright lights, and subjects suffering from genetic ill fortune, neural problems, or the effects of aging.

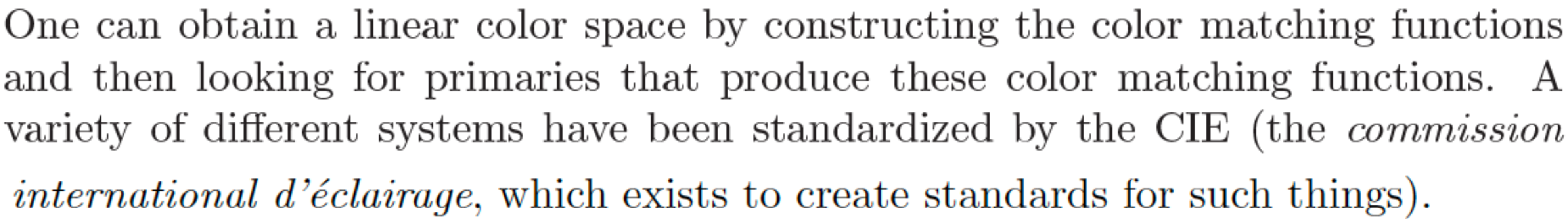
Linear Color Spaces

The natural mechanism for representing color is to agree on a standard set of primaries, and then describe any colored light by the three values of weights that people would use to match the light using those primaries. One can represent surface colors as well by using a standard light for illuminating the surface. This is a *linear color space*. The three primaries P_1, P_2, and P_3 need not be be physically realizable.

Because color matching is linear, predicting the weights that would be needed to match a particular spectral energy density is straightforward. Obtain a *color matching function* for each primary by experiment. The i'th color matching function ($f_1(\lambda)$, $f_2(\lambda)$, and $f_3(\lambda)$) records the weight for the i'th primary matching a unit energy source at wavelength λ. Because the human color system is linear, if a source $S(\lambda)$ is matched by $w_1P_1 + w_2P_2 + w_3P_3$, then

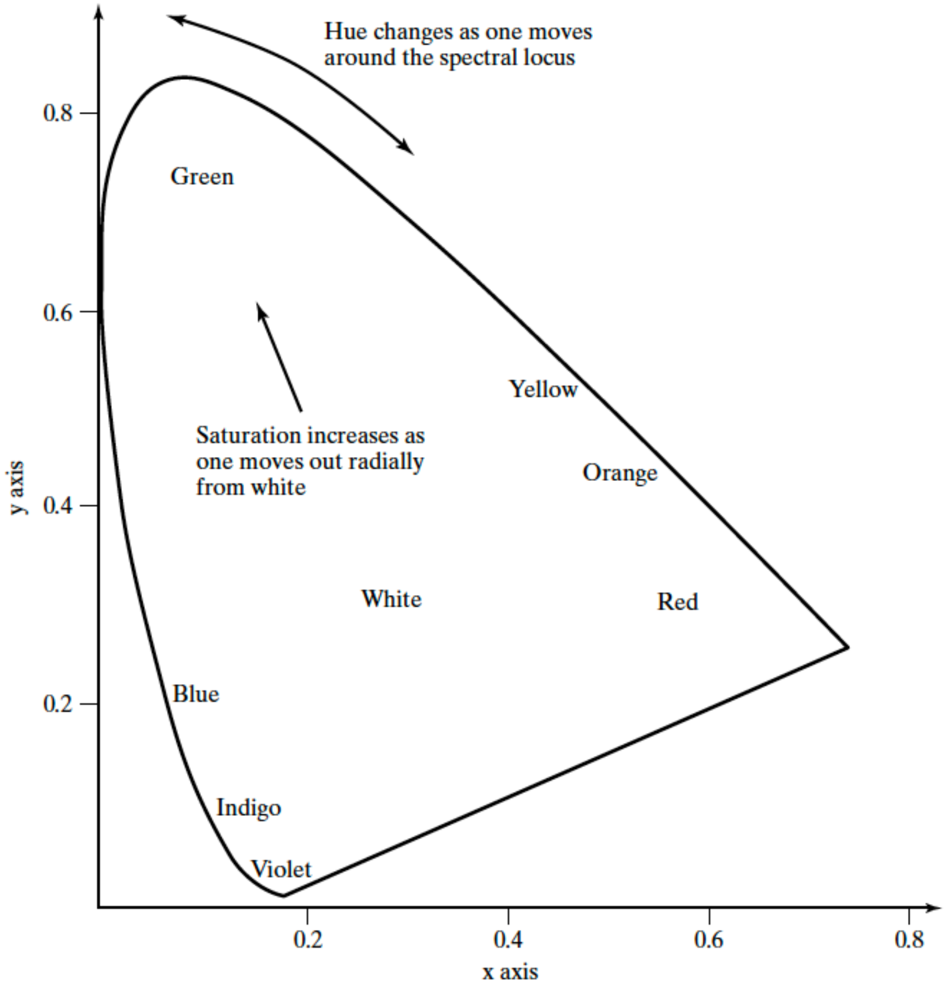
$$w_i = \int f_i(\lambda)S(\lambda)d\lambda.$$

Color space from cmf



One can obtain a linear color space by constructing the color matching functions and then looking for primaries that produce these color matching functions. A variety of different systems have been standardized by the CIE (the *commission international d'éclairage*, which exists to create standards for such things).

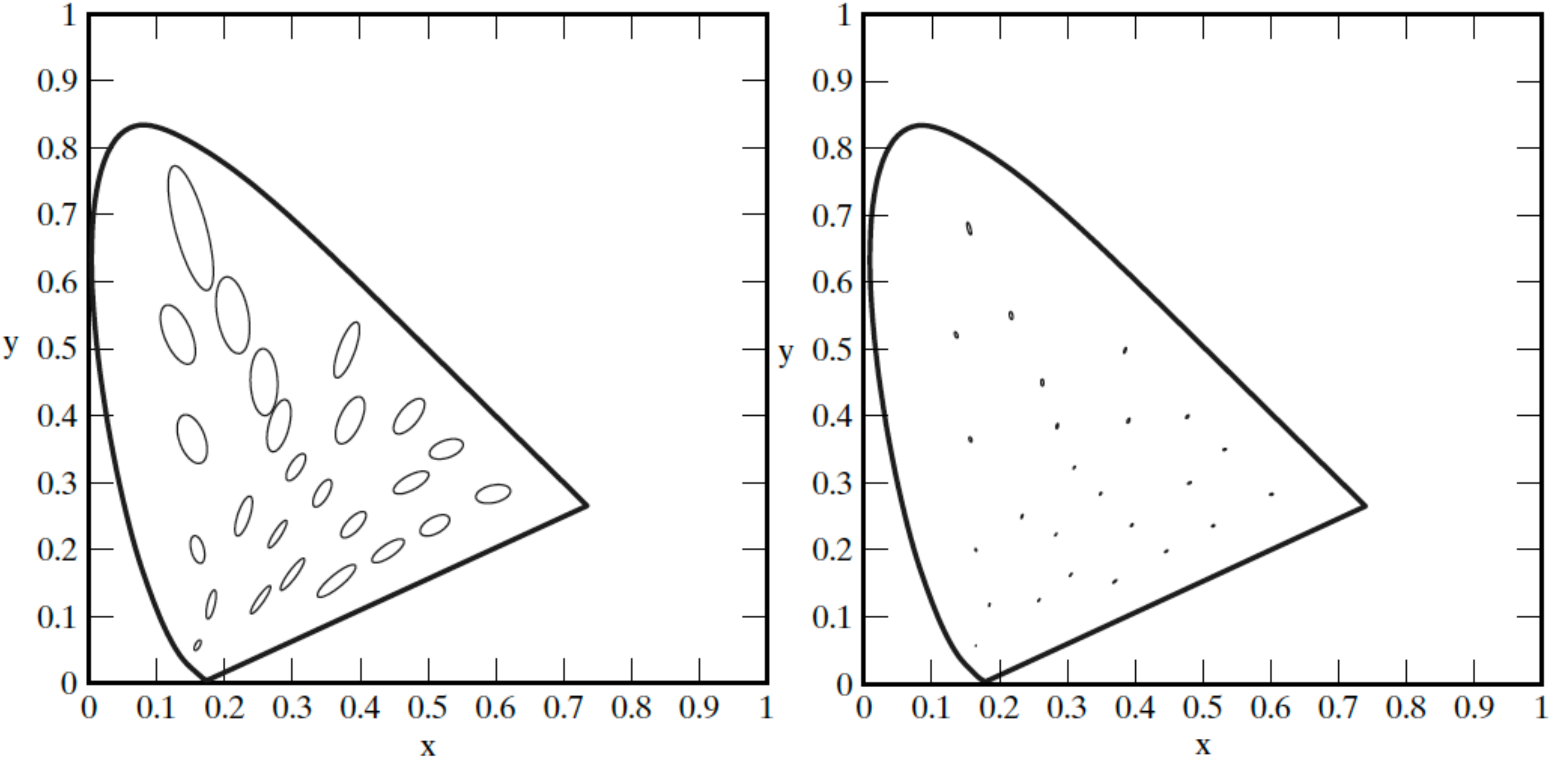
CIE xy



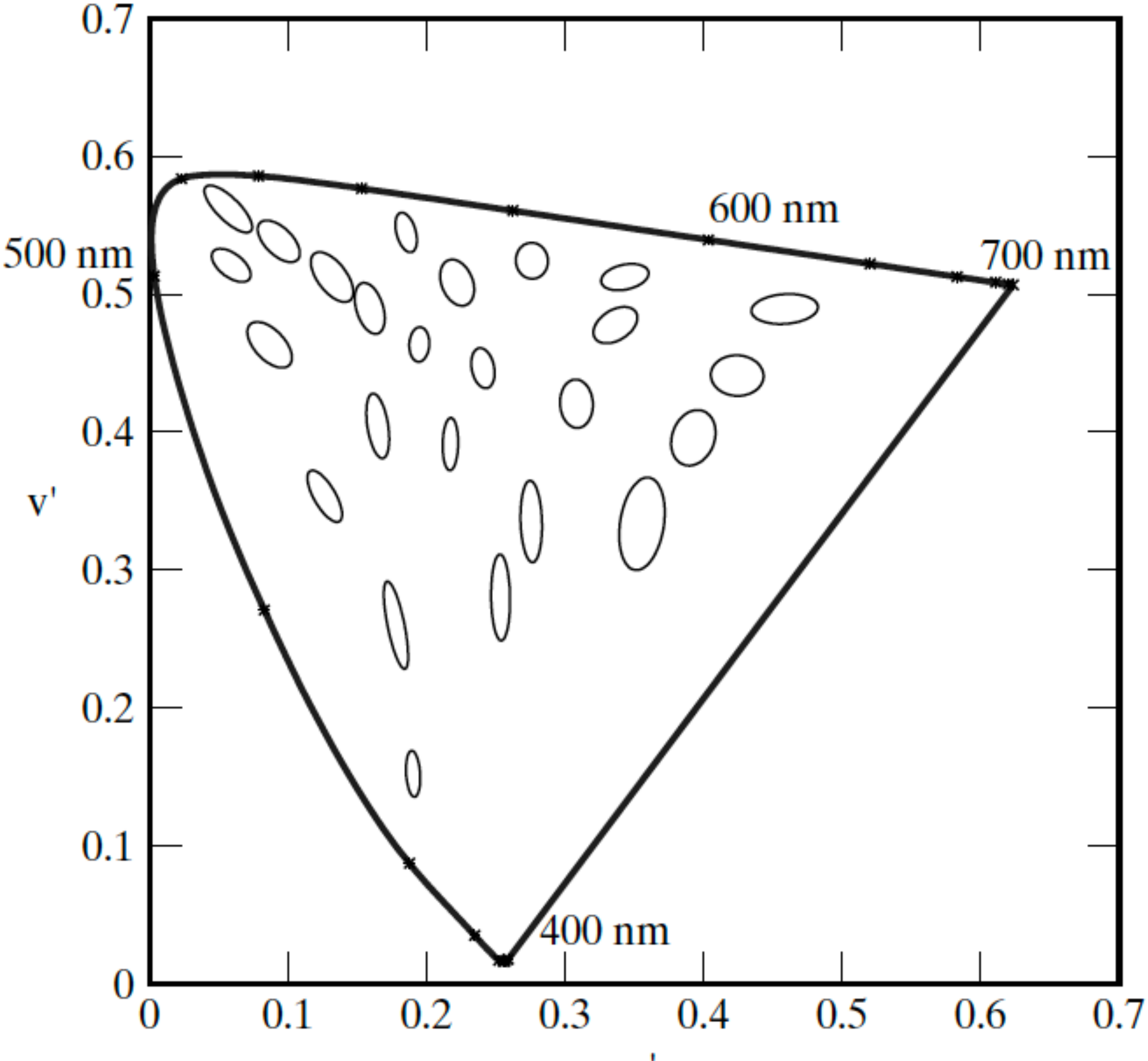
Obtain X, Y, Z from CIE XYZ cmfs then:

$x=X/(X+Y+Z)$
$y=Y/(X+Y+Z)$

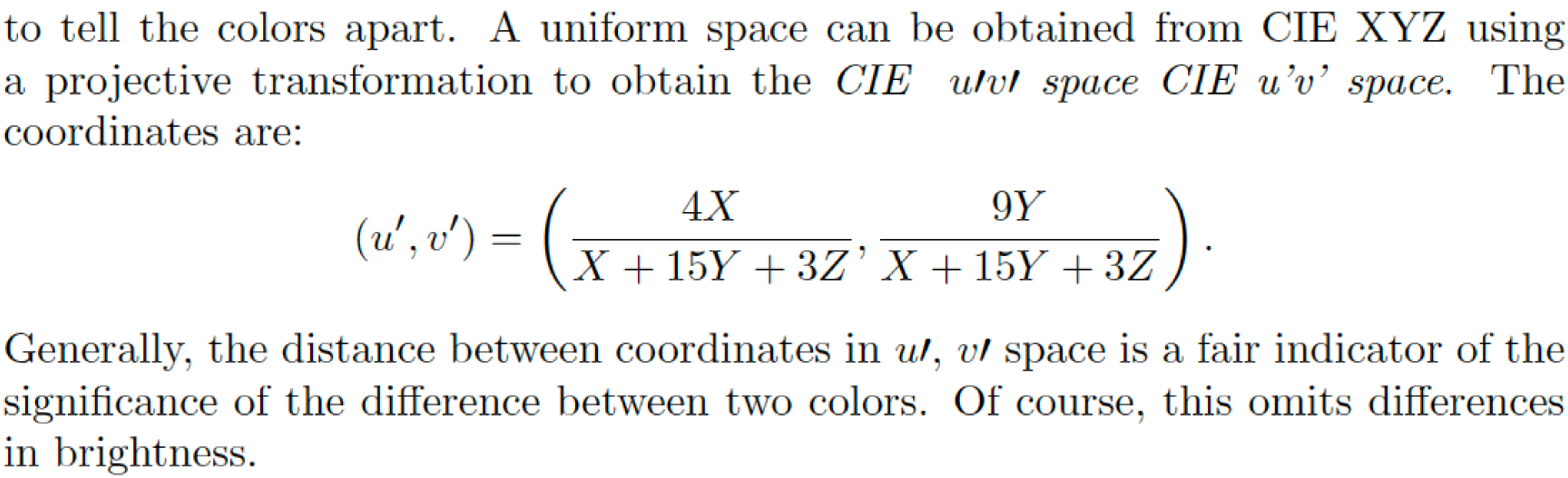
x, y isn’t uniform



CIE u’, v’ is uniform (ish)



CIE u’, v’ is uniform

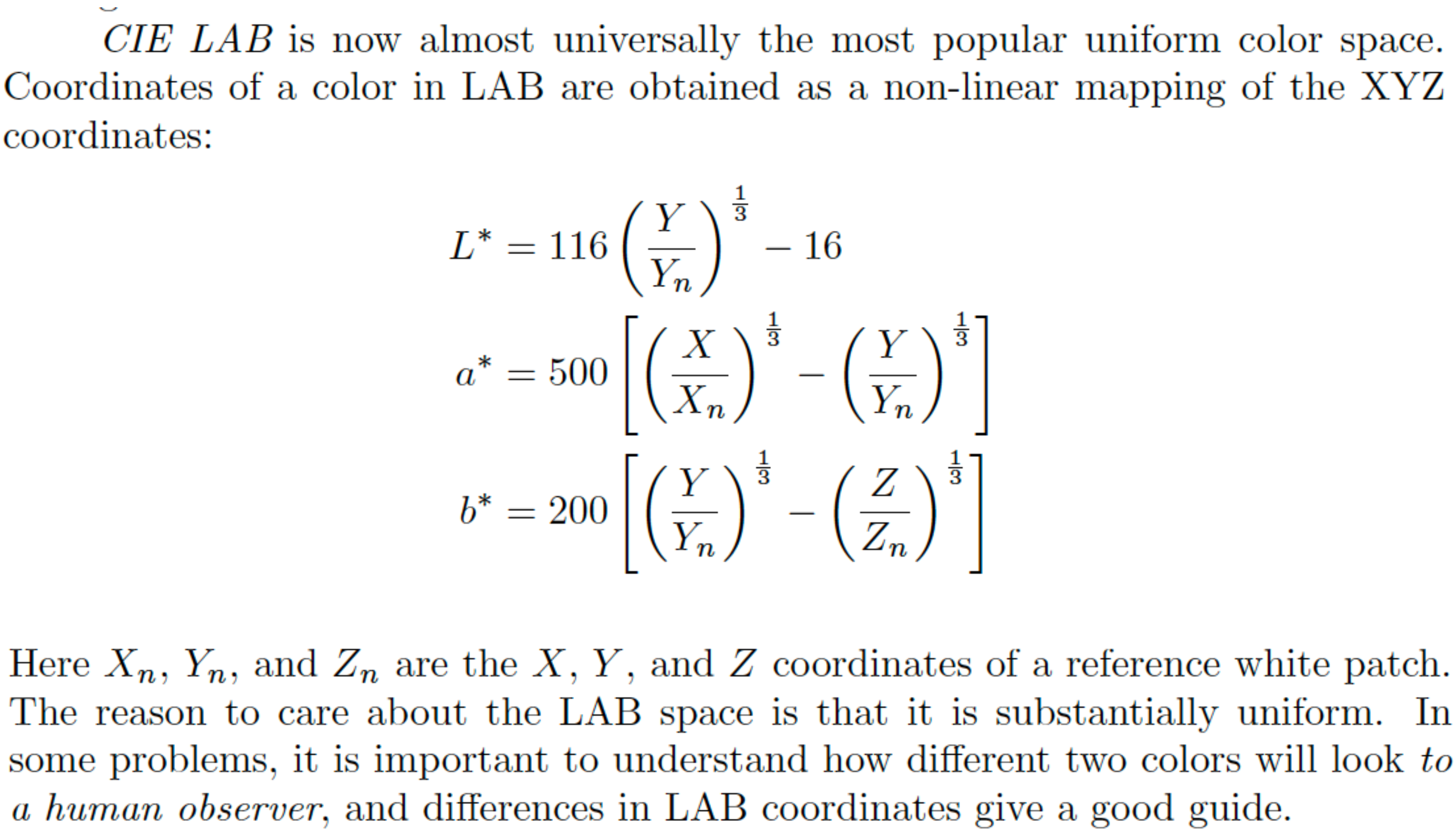


to tell the colors apart. A uniform space can be obtained from CIE XYZ using a projective transformation to obtain the *CIE u′v′ space CIE u’v’ space*. The coordinates are:

$$(u', v') = \left(\frac{4X}{X + 15Y + 3Z}, \frac{9Y}{X + 15Y + 3Z} \right).$$

Generally, the distance between coordinates in u', v' space is a fair indicator of the significance of the difference between two colors. Of course, this omits differences in brightness.

CIE LAB is substantially uniform



CIE LAB is now almost universally the most popular uniform color space. Coordinates of a color in LAB are obtained as a non-linear mapping of the XYZ coordinates:

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16$$

$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]$$

Here X_n, Y_n, and Z_n are the X, Y, and Z coordinates of a reference white patch. The reason to care about the LAB space is that it is substantially uniform. In some problems, it is important to understand how different two colors will look *to a human observer*, and differences in LAB coordinates give a good guide.

HSV is “natural”